

SOIL ROUGHNESS FOR THE REVISED WIND EROSION EQUATION
RWEQ

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ABSTRACT

Soil surface aggregates (random roughness) and ridges (oriented roughness) can reduce soil loss by wind erosion. The soil roughness factor (K') is used to describe the effect of soil roughness on soil loss by wind. The K' in the Wind Erosion Equation (WEQ) model is a ridge roughness value which does not include the random roughness effect and is not modified by rainfall. This study was conducted to develop a soil roughness factor for the Revised Wind Erosion Equation (RWEQ) model. Wind tunnel data was used to generate the roughness factor which included both aggregate (random) and ridge (oriented) roughness. Surface roughness decay functions were used to predict K' (ridge and aggregate levels) after each rainfall event using rainfall amount and storm erosivity index (EI). A function was used to predict K' parallel and perpendicular to the wind for ridged fields. The soil surface roughness measurement obtained from the chain method and ridge height and spacing can be used to estimate K' . A look-up table was developed to obtain K' based on soil surface roughness measurements.

INTRODUCTION

Soil erosion by wind occurs when (1) wind velocity exceeds the threshold required to initiate soil movement, (2) soil particles are small enough to erode, and (3) the soil surface is not protected by crop canopy, residue, and/or roughness (aggregates and ridges). To reduce wind erosion, wind velocity at the surface must be reduced below the threshold velocity required to initiate soil movement. Flat and standing crop residues, crop canopy, wind barriers (Bilbro and Fryrear, 1985; Bilbro and Fryrear, 1988; Chepil and Woodruff, 1963; Lyles and Allison 1976; van de Ven *et al.*, 1989) and soil surface roughness are among the most important factors reducing wind velocity at the surface (Armbrust *et al.*, 1964; Chepil and Woodruff, 1963; Fryrear, 1984).

Soil surface roughness, including ridges and aggregates, reduces wind erosion. Since 1992, U.S. Department of Agriculture, Agricultural Research Service scientists have been developing a predictive model to replace the Wind Erosion Equation (WEQ) model. This new predictive technology, the Revised Wind Erosion Equation (RWEQ), incorporates the most current science in wind erosion (Fryrear *et al.*, 1997).

Chepil and Woodruff (1963) stated that “Lister operation through the processes of increasing the nonerodible fractions and increasing the surface roughness, has reduced wind erosion from a very high amount to an insignificant amount”. Armbrust *et al.* (1964) conducted a wind tunnel study to evaluate the effect of ridges and aggregates on soil erosion by wind. They exposed dune sand mixed with various percentages of gravel, by weight, formed in ridges of various heights, to different levels of wind velocity and collected the eroded soil at the end of the tunnel. They concluded that ridges larger than 0.051 m and smaller than .102 m high eroded little due to trapping of soil particles between ridges. However, they suggested that extensive erosion on ridges higher than .102 m resulted from higher wind velocity at the ridges crests. The Armbrust *et al.* (1964) study was used to derive the K' factor in the WEQ model.

Fryrear (1984) conducted a wind tunnel test to evaluate soil losses from different surfaces. Conditions consisted of a surface with ridges 0 to 25.4 cm high with 0 to 60% of the surface covered with nonerodible aggregates. Soil losses were reduced 90% with ridges 6.3 to 25.4 cm high, 89% with nonerodible soil aggregates covering 60% of the soil surface, and 98% with a combination of large ridges and 40% coverage by aggregates. Data regarding soil loss and roughness from other studies (Chepil and Doughly, 1939; Fryrear and Armbrust, 1969) support these findings.

Zingg *et al.* (1953) measured soil loss with a portable wind tunnel in the field at various sites in New Mexico. They obtained soil loss of 515.6 Mt/ha from a flat sandy soil and about 4.9 Mt/ha from the same field with ridges of 25 cm high and 100 cm apart. According to the Armbrust *et al.* (1964) study, estimated soil loss for this field with ridges would be about 310 Mt/ha. Whereas, according to Fryrear (1984) the estimated soil loss would be about 46 Mt/ha.

Soil roughness has been expressed in different terms by various scientists. Zingg and Woodruff (1951) described an index for soil roughness due to the ridges as follows:

$$K_r = 4 \times \frac{H^2}{S} \quad (1)$$

where

K_r = soil ridge roughness factor, cm
 H = ridge height, cm
 S = ridge spacing, cm.

Allmaras *et al.* (1966) developed a random roughness index (RR) to characterize soil surface roughness due to aggregates. The term “RR” is based on the standard error of adjusted natural log-transformed surface elevations. Before computation of this index, the effect of slope and oriented roughness (OR) is removed. Also, to eliminate possibly erratic measurement effects, 10 percent of highest and lowest height measurements are eliminated.

Saleh (1993) developed a method to measure soil surface roughness using a roller chain. This method is based on the principle that when a chain of given length (L_1) is placed upon a surface, the horizontal distance between chain ends (L_2) will decrease as the roughness increases. Soil surface roughness (C_r) is calculated using the L_2/L_1 ratio as follows:

$$C_r = \left(1 - \frac{L_2}{L_1} \right) \times 100 \quad (2)$$

The current roughness factor (K') in the WEQ program does not include random (aggregates) roughness effects and does not decay by rainfall. The objectives of this study are (I) to incorporate the random roughness (aggregates) effects in the K' , (ii) to incorporate a function to

predict the K' at any wind angle relative to the soil ridges, and (iii) to incorporate functions to modify K' (ridges and aggregates) with rainfall amount and rainfall erosivity index (EI).

METHODS AND MATERIALS

New Roughness Factor (K'):

Data from Fryrear (1984) (Table 1) was used to generate the roughness factor (K') which includes both random (aggregates) and oriented (ridges) roughness. K' was obtained by computing the ratio of measured soil loss from ridged and aggregated surfaces to that of a flat surface. The following conditions are considered in K' .

1. Random roughness (RR): aggregated field with no ridges
2. Oriented roughness (OR): field with only ridges and no significant aggregates
3. Oriented and random roughness: surface covered with both ridges and aggregates

Condition number 3 is more representative of normal field conditions than 1 or 2.

Roughness Parameters:

Surface conditions similar to those used by Fryrear (1984) were recreated as follows:

1. Flat surfaces covered by triangular shaped ridges 0, 6.3, 12.7, and 25.4 cm high on a 1 to 4 height-width ratio.
2. Nonerodible artificial clods 4.5 cm in diameter, 2.5 cm high, paraboloid in shape with flat bottom uniformly distributed on ridges to cover 20, 40, or 60% of the surface.

Surface random roughness was measured by the chain method (Saleh, 1993) as follows:

1. A 0.01 m linked roller chain (ANSI 35 riv. Type) one meter long was laid out on the surface parallel to the ridges (when ridges existed).
2. A caliper rod was used to read the linear distance (L_2).
3. Equation (2) was used to calculate C_r .

With no ridges C_r is chain roughness due to random roughness. The measurement of C_r is made with the chain parallel to the ridges.

Ridge heights (H) were determined from the maximum difference between elevations measured parallel to tillage marks. Ridge spacing (RS) was determined by measuring the distance between ridges. Equation (1) was used to calculate the ridge roughness factor (K_r).

RESULTS AND DISCUSSION

Describing Soil Roughness:

As C_{rr} and K_r increase, soil loss decreases. Table 1 also indicates that ridges (K_r) more effectively reduce wind erosion than random roughness (C_{rr}). To describe the integrated effect of oriented and random roughness on K' , equation (3) was obtained by regressing K' on K_r and C_{rr} from Table 1.

$$K' = e^{[1.88 K_r - 2.44 K_r^{0.934} - 0.124 C_{rr}]} \quad (3)$$

$$R^2 = 0.984, P < 0.001$$

where

- K' = roughness factor (0 for extremely rough surface, 1.0 for flat surface)
- K_r = soil ridge roughness factor, cm (see equation 1)
- C_{rr} = soil random roughness parallel to ridges by the chain method.

Table 2 was developed by computing K' using equation [3] with various K_r and C_{rr} . For example:

1. For a surface with $C_{rr} = 10$ and $K_r = 0$ (no ridges), $K' = 0.29$.
2. For ridges 10 cm high and 40 cm apart, $K_r = 10$ cm (equation [1]). With no aggregates ($C_{rr} = 0$) and a wind direction perpendicular to ridges (0 degree), $K' = 0.12$.
3. For a surface with aggregates ($C_{rr} = 10$) and ridges ($K_r = 10$ cm) and a wind direction perpendicular to ridges (0 degree), $K' = 0.04$.

Soil surface roughness is described for the two dominant directions (parallel and perpendicular to the ridges). Saleh (1994) described a procedure to estimate soil roughness at any given angle (R_c) with respect to ridge orientation as follows:

$$R_c = 1.0 - [3.2E - 4\theta + 3.49E - 4\theta^2 - 2.58E - 6\theta^3] \quad (4)$$

where θ is the angle from the direction perpendicular to the ridges (degrees).

Equation (5) is used to compute K' at any wind direction ranging from perpendicular to parallel to the ridges:

$$K' = e^{[R_c \times (1.86 K_r - 2.411 K_r^{0.934}) - 0.124 C_{rr}]} \quad (5)$$

At a direction parallel to the ridges, ridge effect is negligible and only random roughness prevails. With no ridges ($K_r = 0$) all K' are equal regardless of wind direction. The K' for ridged fields with the wind at 90 degree (parallel to the ridges) equal the K' for no ridge conditions (Table 2). K' at directions of 30, 45, and 60 degrees to perpendicular direction of ridges are also presented (Table 2). For example, for $K_r = 10$ cm (ridges 10 cm high and 40 cm apart) and $C_{rr} = 10$:

- at 0 degree $K' = 0.04$
- 30 degrees $K' = 0.05$
- 45 degrees $K' = 0.06$
- 60 degrees $K' = 0.10$
- 90 degrees $K' = 0.29$ (parallel to the ridges gives random roughness only) .

Soil roughness is a dynamic wind erosion control factor that is readily modified by tillage types and direction and weather.

The RWEQ model decays roughness following a rainfall event. Field and laboratory experiments were conducted to develop the relationship between surface random (C_{rr}) and oriented (K_r) roughness decay as a function of rainfall amount and rainfall erosivity index (EI) (Saleh, 1997). Equation (6) was developed from regressing the log of RRR (ratio of random roughness after rainfall to initial random roughness) on CUMEI and CUMR:

$$RRR = e^{[DF(-0.0009 CUMEI - 0.0007 CUMR)]} \quad (6)$$

$$R^2 = 0.95, P < 0.001$$

where

CUMEI = cumulated EI, *Mj-mm/ha-hr*
 CUMR = cumulated precipitation, *mm*
 DF = decay factor based on soil clay and organic matter content.

The value of DF is obtained as follows:

$$DF = e^{[0.943 - 0.07\%CLAY + 0.0011\%CLAY^2 - 0.674\%OM + 0.1]} \quad (7)$$

where

CLAY = clay content, %
 OM = organic matter, %.

Equation (8) was obtained by regressing ORR (oriented roughness after rainfall/initial oriented roughness) on cumulated rainfall (CUMR) and cumulated EI (CUMEI).

$$ORR = e^{[DF(-0.025 CUMEI^{0.31} - 0.0085 CUMR^{0.567})]} \quad (8)$$

$$R^2 \geq 0.99, P < 0.001$$

Equations (6), (7), and (8) are used in RWEQ to describe the effect of for soil surface random and oriented roughness on soil erosion by wind. For example, for a field with ridges 10 cm height 40 cm apart ($C_{rr} = 10$), 10% clay, and 1% organic matter gives $DF = 0.82$ and $K_r = 10$ cm. After 200 mm of rainfall (assuming $CUMEI = 1500$ *Mj-mm/ha-hr*), $K_r = 7.1$ cm (29% decay), C_{rr} would reduce to 2.96 (71% decay), and K' would increase from 0.03 to 0.11 (Table 2). This means that soil surface roughness would be less effective in controlling erosion after the rainfall event. Soil ridges decay at a much slower rate than aggregates. Therefore, ridges are more effective than aggregates for controlling erosion over extended periods when the wind direction

is perpendicular to ridges, especially for high rainfall areas and irrigated lands. However, one advantage of aggregates is that they protect the soil surface from erosion in all directions.

The soil surface random roughness of a soil surface can be estimated from direct observation, photographs, or from chain method. In describing soil surface roughness, a “non-aggregated” flat soil surface has no effect on wind erosion and $K' = 1.0$ (Table 2). A field with “low aggregation” has a surface composed of a low number of small aggregates (less than 5 cm in diameter, $C_{rr} < 4.0$ and > 1.0) which results in K' values ranging from 0.61 to 0.88 (Table 2). A field with a “medium aggregation” is composed of aggregates of less than 10 cm and greater than 5 cm in diameter ($C_{rr} > 4.0$ and < 10.0) for which K' ranges from 0.61 to 0.29 (Table 2). A field with aggregates greater than 10 cm in diameter is considered as a “high aggregation” field ($C_{rr} > 10.0$) for which K' would be less than 0.29.

SUMMARY AND CONCLUSIONS

Soil roughness is one of the management tools used to control wind erosion. It is now possible to (1) quickly measure soil surface roughness in the field using the chain method, (2) express these measurements in terms of a soil roughness factor (K') for wind erosion models, (3) express the changes in K' at any direction, and (4) decay surface roughness including ridges and aggregates with rainfall amount and rainfall erosivity index (EI), and (5) estimate the protection level that soil surface roughness might provide at different directions to the ridges during a wind erosion event using the look-up table. As Chepil and Woodruff (1963) stated soil roughness can reduce wind erosion significantly by increasing nonerodible aggregates and raising the threshold wind velocities at the surface. Crop residues are the best management practice to control wind erosion when appropriate environmental conditions (*e.g.* rainfall) exist. However, in semiarid regions such as the Southern Great Plains, where the production of adequate residue is limited, soil surface roughness induced by tillage is the primary means for effective wind erosion control.

REFERENCES

- Allmaras, R.R., R.E. Burwell, W.E. Larson, and R.F. Holt. 1966. Total porosity and random roughness of the interrow zone as influenced by tillage. USDA Conser. Res. Rep. 7.
- Armbrust, D.V., W.S. Chepil, and F.H. Siddoway. 1964. Effect of ridges on erosion of soil by wind. Soil Sci. Soc. Am. Proc. 28(4):557-560.
- Bilbro, J.D., and D.W. Fryrear. 1985. Effectiveness of residues from six crops for reducing wind erosion in a semiarid region. J. Soil Water Cons. 40(4):358-360.
- Bilbro, J.D., and D.W. Fryrear. 1988. Plant material for windbarriers in semiarid regions. p. 150-157. *In* Proc. Wind Erosion Conference, Lubbock, TX. April 11-13, 1988.
- Chepil, W.S., and J.L. Doughly. 1939. Wind tunnel experiments on soil drifting. Report regional Commission on Soil Drifting, Swift Current, Saskatchewan. P. 19., July 11, 1939.
- Chepil, W.S., and N.P. Woodruff. 1963. The physics of wind erosion and its control. Adv. Agron. 15:211-302.
- Fryrear, D.W. 1984. Soil ridge-clods and wind erosion. Trans. ASAE. 27(2):445-448.
- Fryrear, D. W., and D.V. Armburst. 1969. Cotton gin trash for wind erosion control. Tx. Agric. Expt. Sta. MP-928. Texas Agricultural Experiment Station.
- Fryrear, D.W., A. Saleh, and J.D. Bilbro. 1997. A single event wind erosion model. Trans. ASAE (In progress).
- Lyles, L., and B.E. Allison. 1976. The protective role of simulated standing stubble. Trans. ASAE 19(1):61-64.
- Saleh, A. 1993. Soil roughness measurement: Chain method. J. Soil Water Cons. 48(6): 527-529.
- Saleh, A. 1994. Measuring and predicting ridge-orientation effect on soil surface roughness. Soil Sci. Soc. Am. J. 58(4):1228-1230.
- Saleh, A. 1997. Soil surface roughness decay by rainfall amount and erosivity index (EI). Soil Science. (In review)
- van de Ven, T.A.M., D.W. Fryrear, and W.P. Spaan. 1989. Vegetation characteristics and soil loss by wind. J. Soil Water Cons. 44(4):347-349.
- Woodruff, N. P., and F.H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Am. Proc. 29(5):602-608.

Zingg, A.W., W.S. Chepil, and N.P. Woodruff. 1953. Analyses of wind erosion phenomena in Roosevelt and Curry counties, New Mexico. Soil Conservation Service. Albuquerque, NM. M 436.

Zingg, A.W., and N.P. Woodruff. 1951. Calibration of a portable tunnel for simple determination of roughness and drag on field surfaces. Agron. J. 43(4):191-193.

Table 1. Soil ridge roughness (K_r) and soil loss data from Fryrear (1984), chain reading (C_{rr}), and K' calculated by dividing each soil loss by 285 (soil loss for flat, smooth surface).

	C_{rr}							
	0		7.97		11.65		17.50	
K_r <i>cm</i>	Soil Loss <i>g/10 min</i>	K' <i>cm</i>	Soil Loss <i>g/10 min</i>	K' <i>cm</i>	Soil Loss <i>g/10 min</i>	K' <i>cm</i>	Soil Loss <i>g/10 min</i>	K' <i>cm</i>
0.0	285.0	1.0	125.5	0.44	52.7	0.19	14.5	0.05
6.3	42.2	0.15	28.9	0.10	23.0	0.08	10.2	0.04
12.7	29.2	0.10	10.2	0.04	9.9	0.04	3.0	0.01
25.4	30.7	0.11	9.9	0.04	5.6	0.02	3.8	0.01

Table 2. Soil roughness factor (K') using equation (3) with K_r and C_{rr} at 0, 30, 45, 60, and 90 degrees perpendicular direction to the ridges.

K_r cm	Angle deg.*	C_{rr}													
		0	2	4	6	8	10	12	14	16	18	20	22	24	26
0	0	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
	30	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
	45	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
	60	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
2.5	0	0.36	0.28	0.22	0.17	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01
	30	0.45	0.35	0.27	0.21	0.17	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02
	45	0.52	0.40	0.32	0.25	0.19	0.15	0.12	0.09	0.07	0.06	0.04	0.03	0.03	0.02
	60	0.65	0.51	0.40	0.31	0.24	0.19	0.15	0.12	0.09	0.07	0.05	0.04	0.03	0.03
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
5.0	0	0.21	0.17	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.03	0.02	0.01	0.01	0.01
	30	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04	0.03	0.02	0.02	0.01	0.01
	45	0.35	0.28	0.21	0.17	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01
	60	0.50	0.39	0.30	0.24	0.18	0.14	0.11	0.09	0.07	0.05	0.04	0.03	0.03	0.02
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
7.5	0	0.15	0.12	0.09	0.07	0.06	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01
	30	0.21	0.16	0.13	0.10	0.08	0.06	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01
	45	0.26	0.21	0.16	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01
	60	0.40	0.31	0.24	0.19	0.15	0.12	0.09	0.07	0.06	0.04	0.03	0.02	0.02	0.02
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
10.0	0	0.12	0.09	0.07	0.06	0.04	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
	30	0.16	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01
	45	0.21	0.16	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01
	60	0.33	0.26	0.20	0.16	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
12.5	0	0.10	0.08	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	30	0.14	0.11	0.07	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01
	45	0.17	0.14	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01
	60	0.28	0.22	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
15.0	0	0.10	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	30	0.12	0.09	0.07	0.06	0.04	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01
	45	0.15	0.12	0.09	0.07	0.06	0.07	0.06	0.03	0.02	0.03	0.01	0.01	0.01	0.01
	60	0.25	0.19	0.15	0.12	0.09	0.02	0.02	0.04	0.03	0.01	0.02	0.02	0.01	0.01
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
17.5	0	0.09	0.07	0.06	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	30	0.11	0.08	0.07	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	45	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
	60	0.22	0.17	0.13	0.10	0.08	0.06	0.05	0.04	0.03	0.2	0.01	0.01	0.01	0.01
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04
20.0	0	0.09	0.07	0.06	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	30	0.10	0.08	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	45	0.12	0.09	0.07	0.06	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01
	60	0.19	0.15	0.12	0.09	0.07	0.06	0.04	0.03	0.03	0.2	0.01	0.01	0.01	0.01
	90	1.00	0.78	0.61	0.47	0.37	0.29	0.23	0.18	0.14	0.11	0.08	0.07	0.05	0.04

* Angle is measured in degrees from direction perpendicular to the ridge.